U.S. Department of Energy
Office of Fossil Energy • Federal Energy Technology Center

# Gasification Technologies

## Clean & Affordable Energy Systems

FETC

# Gasification Technologies, Energy Systems for the New Millennium

**Gasification technologies represent the next generation of solid feedstock-based energy production systems.** Gasification breaks down virtually any carbon-based feedstock into its basic constituents. This enables the separation of pollutants and greenhouse gases to produce clean gas for efficient electricity generation and production of chemicals and clean liquid fuels.

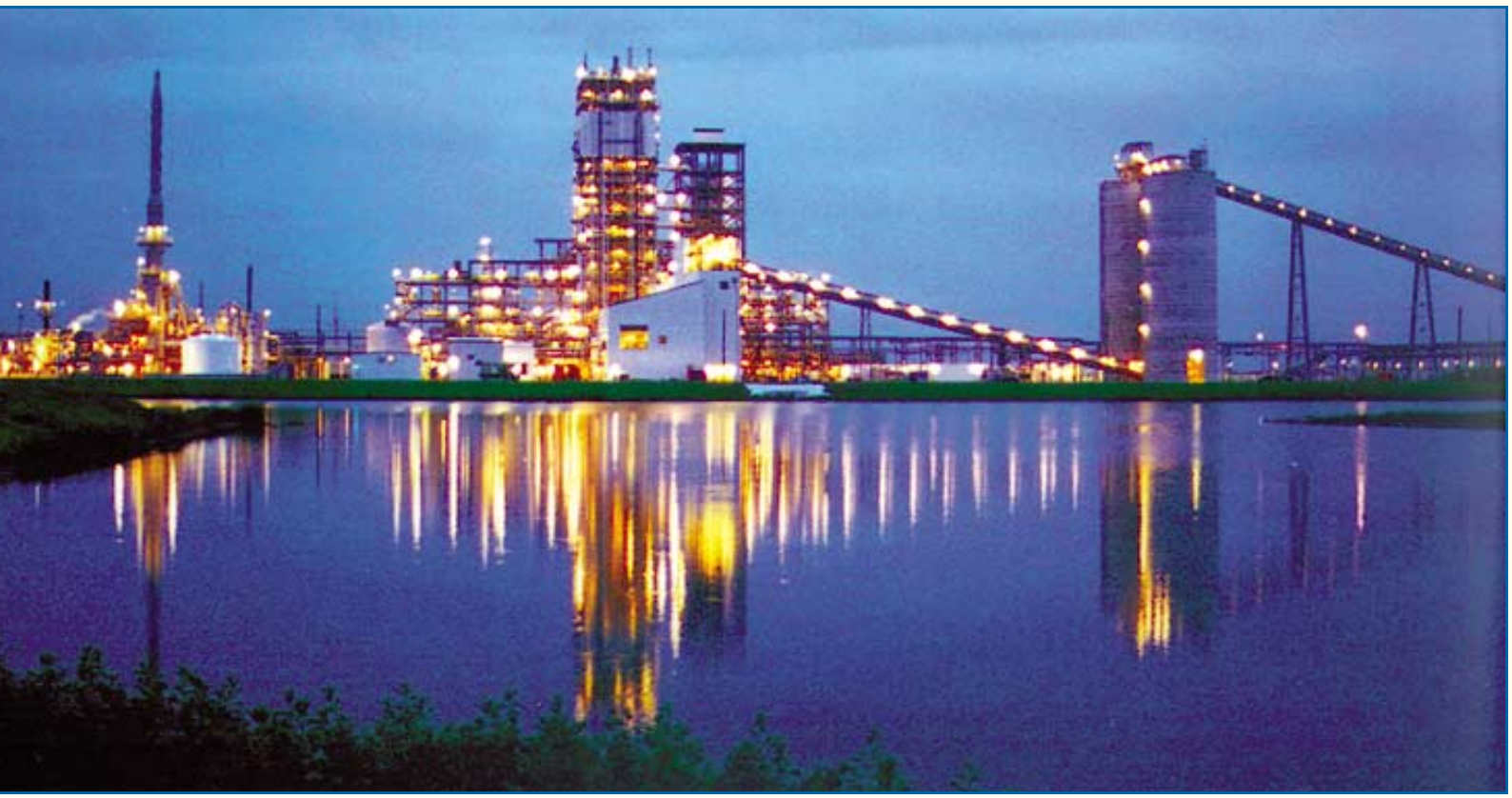
## Benefits

- **Feedstock Flexibility**
- **High Efficiency**
- **Near Zero Pollutants**
- **Product Flexibility**

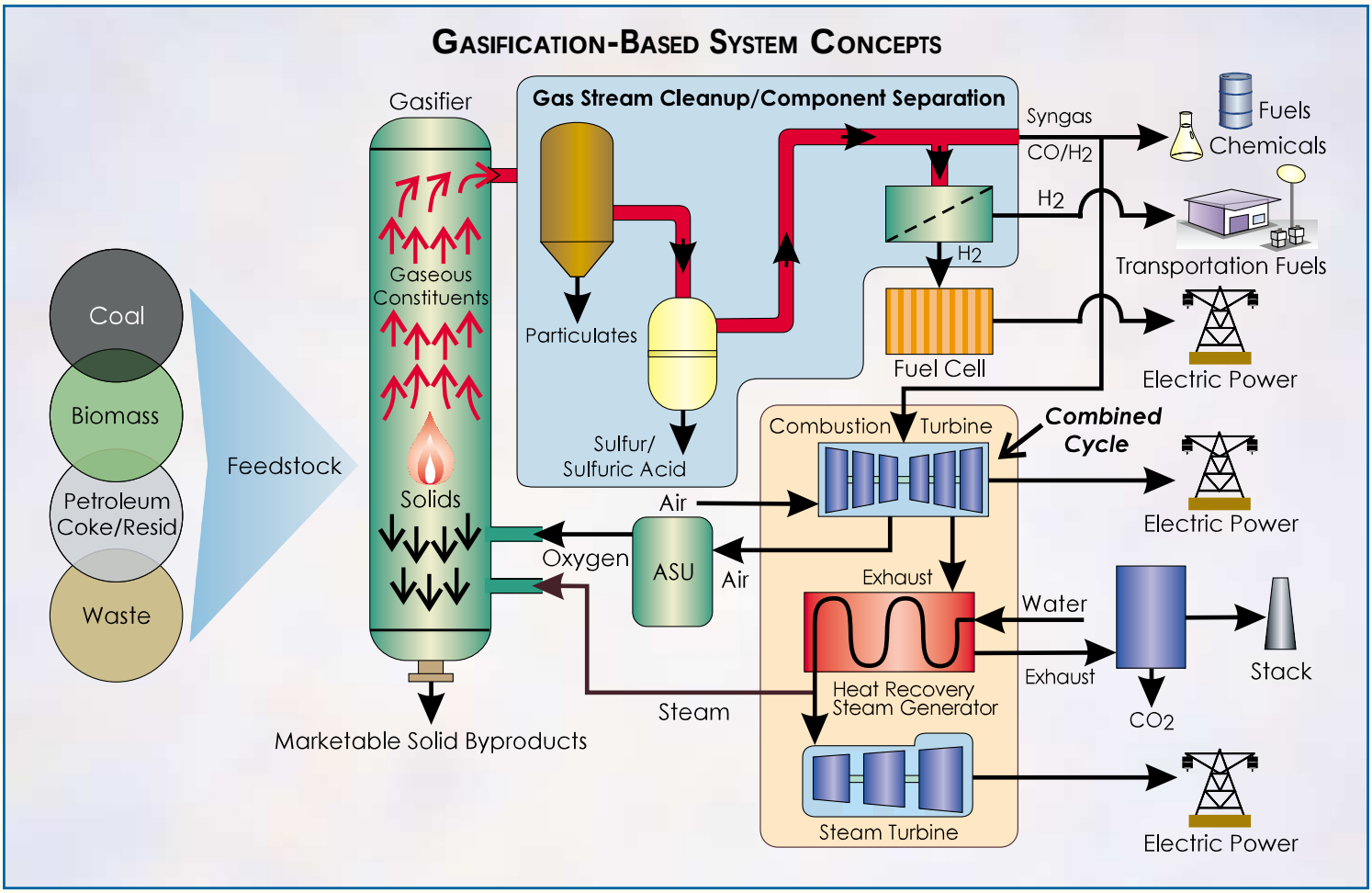
**Commercial-scale integrated gasification combined-cycle (IGCC) plants operating in the United States, and others around the world, are signaling a new age in electric power generation.** Market forces, which are replacing regulatory structures, and regional and global environmental concerns are resulting in expanded IGCC applications. IGCC is both feedstock and product flexible, produces almost no pollutant emissions, and facilitates $CO_2$ removal. As a result, single feedstock, single commodity, steam-powered electric generation is being replaced by more versatile integrated energy technologies.

**IGCC leverages the advantages of combustion turbine/combined cycle (CT/CC) operation and vastly expands the fuel base beyond natural gas to include more abundant and lower cost resources.** CT/CC combines highly efficient combustion turbines with steam turbines, by using the gas turbine exhaust to generate steam, which produces the most efficient and economic electricity available today. Currently, natural gas is the predominant fuel for CT/CC units. Integration of a gasifier allows use of coal, biomass and agricultural, forestry, municipal, and refinery wastes. This flexibility offers the potential to reduce cost and enhance the overall environmental benefits.

**The capability to co-produce electricity and a slate of fuels and chemicals makes the technology economically attractive to a broad range of industrial applications.** Product flexibility enables gasification technologies to be integrated into industrial applications for multiple commodity production and increased revenue. Gasifier technology applications include integration into chemical plants and refineries. The attributes of IGCC make it particularly attractive in coal dependent Asia, where nearly half of the world's energy increase is seen to occur as Asia expands its industrial base over the next two decades.



*Tampa Electric Company's Polk Power Station, 250 MWe IGCC*




## How Gasification-Based Systems Work

The heart of gasification-based systems is the gasifier. The gasifier converts hydrocarbon feedstock into largely gaseous components by applying heat under pressure in the presence of steam. Partial oxidation of the feedstock, through injection of air or oxygen into the gasifier, provides the heat. Together the heat and pressure break the bonds between feedstock constituents and precipitate chemical reactions, producing "syngas."

Minerals in the feedstock (ash) separate and leave the bottom of the gasifier either as an inert glass-like slag or other marketable solid product. Only a small fraction of the ash becomes entrained, which requires removal downstream. Other potential pollutants, such as sulfur compounds, form hydrogen sulfide, from which sulfur is easily extracted, typically as elemental sulfur or sulfuric acid, both valuable byproducts. $NO_x$ is not formed in the reducing environment of the gasifier. Ammonia formed by nitrogen/hydrogen reaction is easily stripped by process water, as are chlorides that might otherwise form acids.

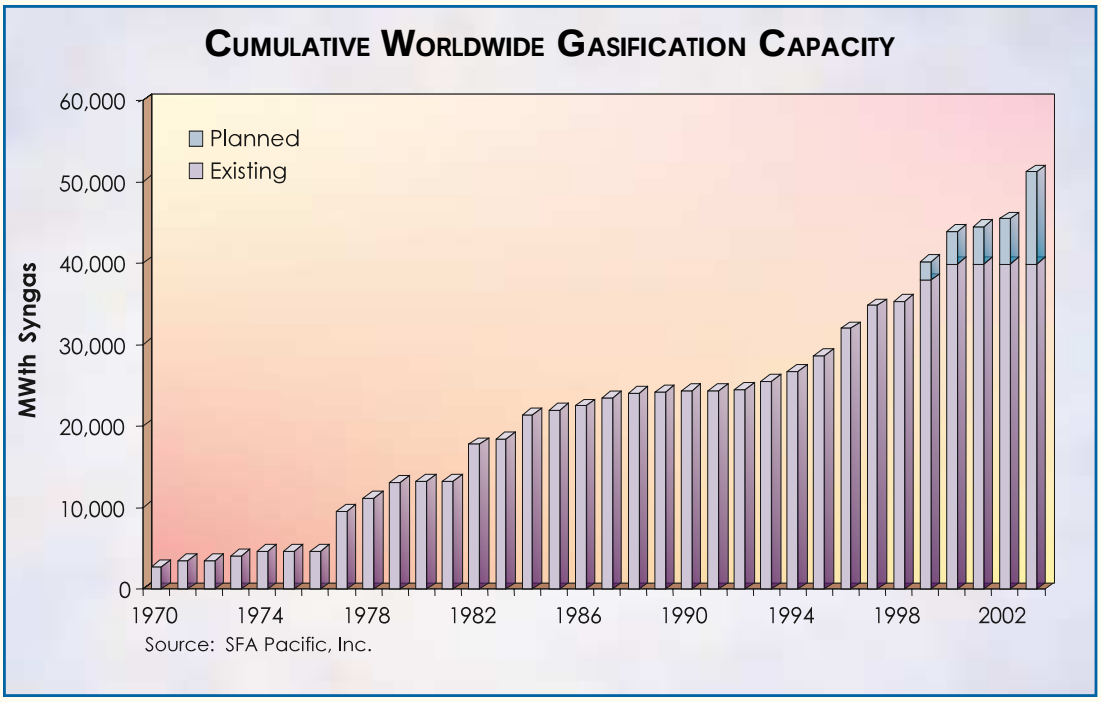
In integrated gasification combined-cycle (IGCC) systems, the clean syngas remaining after pollutant separation is used, in whole or in part, to fuel a combustion turbine. The combustion turbine drives an electric generator, provides air under pressure to the gasifier, and produces heat (exhaust) to generate steam for steam turbine electric power. This combined use of combustion and steam turbines significantly boosts generation efficiency. All or part of the clean syngas can also be used to:

- Produce a broad range of chemicals and clean fuels using established processes;
- Fuel highly efficient fuel cells, the waste heat from which can be used to generate steam in a combined cycle mode; and
- Provide hydrogen, through separation methods, as a fuel or for refinery applications.

Gasification offers feedstock and product flexibility, the potential for greater than 60 percent efficiency, and near zero pollutant emissions. The high process efficiency limits $CO_2$ production and because $CO_2$ occurs in concentrated form, this allows for its capture.

# Worldwide Acceptance

Convergence of a number of factors is prompting rapid emergence of gasification-based power worldwide — IGCC. This emergence adds to an already important role gasification technologies have played in the production of chemicals and transportation fuels.




*Cumulative worldwide gasification capacity is shown here in MWth, a measure of syngas thermal energy. There are currently 116 commercial gasification projects, in operation or under construction, incorporating 385 gasifiers; and another 22 commercial projects planned, incorporating 34 gasifiers. Power generation applications represent the greatest percentage of planned gasification additions.*

Feedstock and product flexibility enabled IGCC and other gasification technologies to achieve market entry through the use of low-cost opportunity feedstocks, such as petroleum coke and waste, and through co-production of chemicals and fuels. Follow-on replications and design refinements are reducing capital costs and technical and market risk. As a result, IGCC is beginning to have an economic, as well as environmental performance edge over pulverized coal-based systems for power generation applications. Continued growth in gasification is driven by a number of factors.

## Drivers

- Market forces are replacing government regulations that artificially constrain approaches to electricity generation, placing emphasis on economic performance;
- Premiums are being placed on environmental performance by not only requiring minimum standards, but setting "externality" values on avoided pollutant and greenhouse gas emissions;
- Demand is increasing for cleaner transportation fuels, requiring more hydrogen;
- Demand is escalating for chemicals as the U.S. seeks to maintain industrial growth and coal dependent Asia undergoes exponential industrial expansion;
- Solid waste disposal and sewage sludge disposal are carrying increasingly severe economic penalties, placing value on their avoidance and use as a feedstock; and
- Requirements and incentives for renewables use, such as biomass, are coming into effect to address global climate change concerns.

## Examples of Leveraging Gasification Feedstock and Product Flexibility

**Refineries —** Petroleum coke or heavy oil resid (refinery wastes) are gasified to avoid waste disposal costs and to produce electricity, steam, hydrogen, and raw syngas for refinery process energy and chemistry.

**Pulp and paper production —** Black liquor, which contains both dissolved organic constituents from the wood and process chemicals, is gasified to generate energy from the organic compounds and to separate and recover the process chemicals.

**Co-production —** Electricity and higher value fuels or chemicals are produced to meet market demands. Also, because of the product flexibility, the capital investment in plant can be optimized and inefficient cycling avoided.

# The Gasification Technology Program

The U.S. Department of Energy (DOE) Office of Fossil Energy and Federal Energy Technology Center (FETC) have been instrumental in moving gasification technologies from the laboratory to the marketplace. Through government/industry partnerships, DOE/FETC is sharing the cost and risk of the research, development, and demonstration requisite to bringing IGCC to commercial fruition.

DOE/industry cost-shared IGCC demonstration projects, representing a diversity of gasifier types and cleanup systems, are pioneering introduction of this new approach to power generation in the U.S. and providing invaluable performance data.

- Two are currently operating in a commercial dispatch mode at nominally 250 MWe net capacity.
- A third nominally 100 MWe unit initiated operation; and a fourth 400 MWe IGCC project is in planning.
- Another project is demonstrating production of 80,000 gallons/day of methanol in an IGCC application.

The demonstrations serve as building blocks for even more advanced systems. Paralleling the demonstrations is a research and development (R&D) program designed to take IGCC beyond market entry into broad-based deployment. Emphasis is placed on reducing cost, increasing efficiency, expanding feedstock and product flexibility, and achieving near zero pollutants. Moreover, higher efficiency and concentrated gas streams provide a platform for controlling $CO_2$ emissions.

*Development facilities are used in pursuit of R&D and to support demonstrations, serving as focal points for cooperative research with industry in establishing a reliable operating data base. The Power Systems Development Facility, located in Wilsonville, Alabama and operated by Southern Company Services (left), focuses on power system components and subsystems.*

*Air Products and Chemicals liquid phase methanol (LPMEOH™) process has been developed to enhance IGCC power generation by producing a clean burning, storable liquid fuel — methanol — from coal-derived syngas. An 80,000 gallon-per-day demo unit is operating at the Eastman Chemical Company in Kingsport, Tennessee.*

### Cost and Efficiency Targets

| Year | Capital Costs ($/kW) | Efficiency (%HHV) |
|---|---|---|
| 2000 | 1,250 | 42 |
| 2008 | 1,000 | 52 |
| 2015 | 850 | >60 |

## R&D Thrusts

### Gasification Systems Technology

- Exploring **advanced gasifier** systems to further fuel flexibility, efficiency, and economic and environmental performance;
- Evaluating novel **gas cleaning and conditioning** concepts to meet rigid syngas quality specifications for fuel cells and catalytic conversion of processes;
- Investigating **advanced gas separation** alternatives to energy intensive methods, such as ceramic membranes, for separating oxygen, hydrogen, and $CO_2$ from process gas streams; and
- Improving **value added products** and processes to enhance byproduct revenues.

### Systems Analysis/Product Integration

- Providing the technical assistance and conducting the R&D necessary to support the **demonstrations**;
- Conducting **economic analyses, process performance assessments, and market studies** to focus on key R&D; and
- Implementing an aggressive **outreach program** to: inform customers and stakeholders about the program; seek feedback on program efforts; and nurture continued R&D partnerships.

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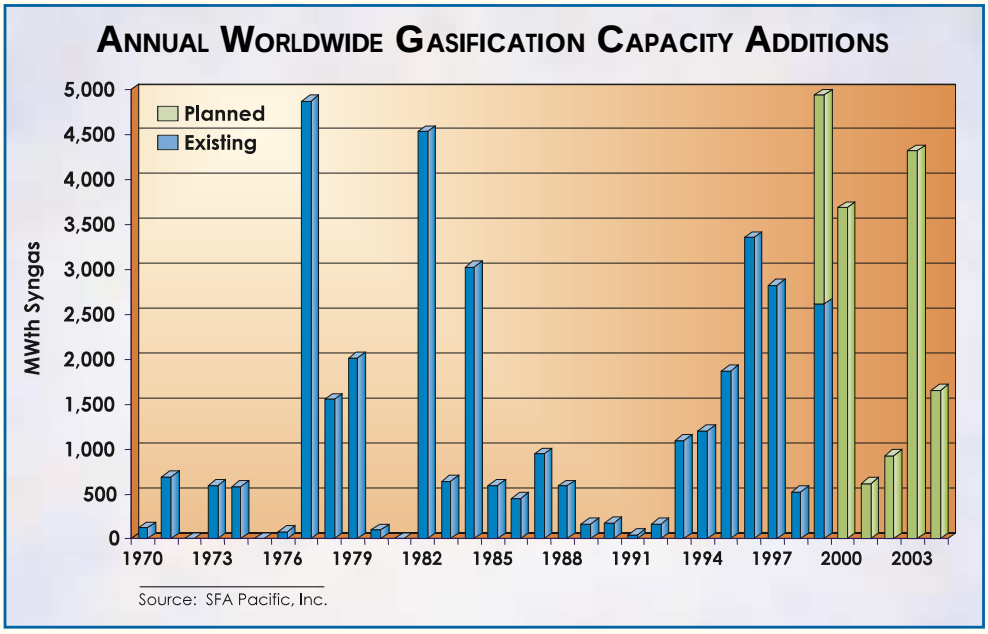
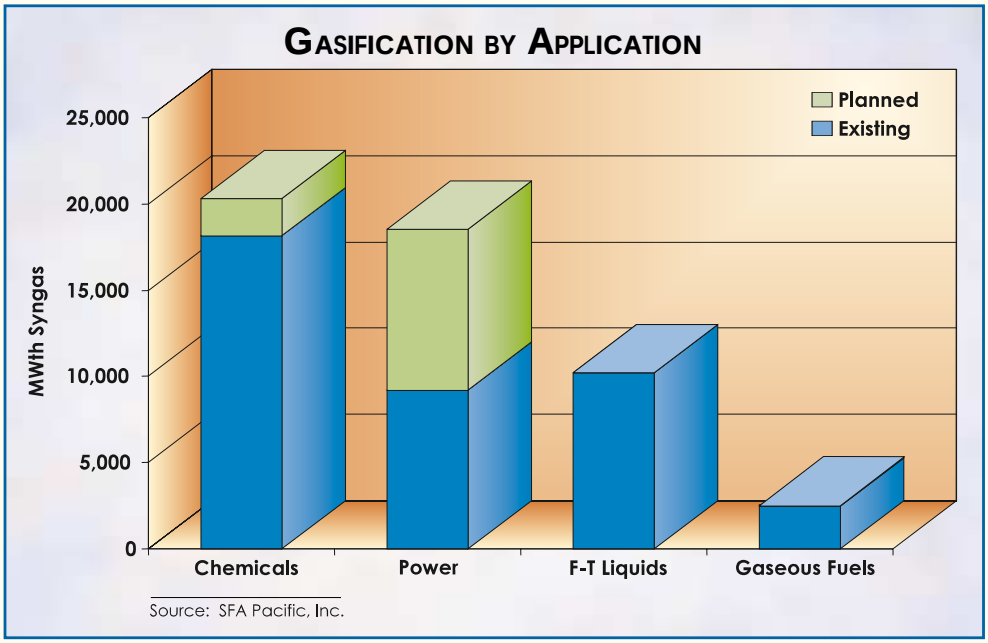



*A recent surge in gasification-based technology applications has raised existing capacity to around 40,000 MWth (a measure of syngas heat energy). Much of the movement has been in the power industry.*




*Power applications continue to dominate planned capacity additions, representing 9,200 MWth of the total 11,500 MWth increase, or 80 percent.*

*Note: One MWth is equivalent to 3,413X10$^{6}$ Btu/hr.*